Ocean Data Assimilation for Coupled Models

Patricia A. Phoebus
Naval Research Laboratory
Monterey, CA 93943-5502
phone: (831) 656-4758 fax: (831) 656-4314 email: phoebus@nrlmry.navy.mil

James A. Cummings
Naval Research Laboratory
Stennis Space Center, MS 39529-5004
phone: (831) 656-1935 fax: (831) 656-4769 email: cummings@nrlmry.navy.mil

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LONG-TERM GOALS

The long-term goal of this and companion projects is to improve our ability to analyze and predict the upper ocean/lower atmosphere environment, using sophisticated techniques that can exploit data from all available sources. This ability is fundamental to meeting DOD's needs for real-time analysis and improved air/sea simulation and prediction on a variety of scales, including mesoscale to tactical scale support in littoral environments and on the battlefield. To meet these needs, the Naval Research Laboratory is developing the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS), and has already transitioned the atmospheric prediction system and ocean analysis components to operations.

OBJECTIVES

The objective of this particular project is to develop the globally-relocatable, three-dimensional multivariate ocean data analysis component of COAMPS to provide a capability that will 1) provide the best possible initial conditions for the mesoscale ocean forecast model and 2) provide accurate lower boundary conditions for the atmospheric forecast model. The emphasis is on the development of a complete ocean data assimilation capability, where oceanographic data from a variety of sources are assimilated into an ocean forecast model at regular intervals in a dynamically consistent fashion.

APPROACH

Plans for developing the next-generation ocean data assimilation system include leveraging the experience of both the atmospheric and oceanographic communities. We are expanding the univariate optimum interpolation (OI) approach to a fully multivariate, three-dimensional OI ocean data assimilation capability (3D MVOI), where adjustments to the ocean's mass field will be correlated with adjustments to the ocean's flow field, and a short-term model forecast will provide the analysis background field. This capability will set the stage for utilizing even more sophisticated techniques in the future, such as 3D and 4D variational data assimilation. As we extend the analysis capability to assimilate multiple variable types from a number of different sources, new quality control techniques must be developed for those observations and the appropriate observation errors must be evaluated. We will progress from loose to tight coupling between the ocean and the atmospheric systems, and all

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14. ABSTRACT
The long-term goal of this and companion projects is to improve our ability to analyze and predict the upper ocean/lower atmosphere environment, using sophisticated techniques that can exploit data from all available sources. This ability is fundamental to meeting DOD's needs for real-time analysis and improved air/sea simulation and prediction on a variety of scales, including mesoscale to tactical scale support in littoral environments and on the battlefield. To meet these needs, the Naval Research Laboratory is developing the Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS), and has already transitioned the atmospheric prediction system and ocean analysis components to operations.

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development will ultimately be tested within the structure of the entire coupled prediction system. In addition, we will ensure that the software developed is fully compatible with other existing and planned components of COAMPS, thereby providing a seamless depiction of the air/sea environment within a single package.

WORK COMPLETED

The COAMPS 3D MVOI has been fully integrated into the COAMPS software. The latest version of the 3D MVOI is compatible with the Modular Ocean Data Assimilation System (MODAS) synthetic profile databases developed at NRL Stennis. Improvement of the 3D MVOI analysis system continued in FY01, with an emphasis on developing the tools and techniques required to initialize and cycle the ocean analysis with an ocean forecast model in the both the regional COAMPS system and in the new coupled Navy Operational Global Atmospheric Prediction System (NOGAPS). In the regional system, the ocean forecast model is the Navy Coastal Ocean Model (NCOM) and, in the global system, the ocean forecast component is the Parallel Ocean Program (POP).

Implementation of a sequential incremental update cycle of the analysis and the NCOM and POP forecast models required software to be developed that interfaced the model restart files valid at the update time with the analyzed increments. Since the 3D MVOI is executed on the same horizontal and vertical grid as the POP model, this process did not require an additional, suboptimal interpolation step when updating POP. However, NCOM is executed using a hybrid vertical coordinate consisting of a variable number of sigma layers and pressure levels. This vertical coordinate system requires an interpolation of the analyzed increments at the analysis pressure levels to the NCOM sigma levels. For both POP and NCOM, the analyzed increments are applied equally to the two time steps saved in the model restart files. This procedure effectively changes the amplitude but not the trajectory of the model forecast in time.

Different procedures were developed to initialize the two forecast models. Initialization of the POP model is started by cycling the ocean analysis for five days until the innovation errors stabilize. The POP initialization and POP relaxation files are set to the analyzed temperature and salinity fields, and the POP model is then forced for 5 days with time-averaged wind stresses to spin-up the velocities. During this period the forecast temperature and salinity fields are relaxed to the analyzed temperature and salinity with a 5-day time scale. At the end of this procedure the POP model velocity fields are consistent with the analyzed mass fields. NCOM is initialized by first performing an ocean analysis from a climatological background field using expanded data time windows. The analyzed mass and velocity fields on pressure levels are interpolated to the NCOM sigma/pressure levels and a static stability test is performed. Salinity is adjusted to achieve neutral buoyancy, if required. NCOM is then run in prognostic mode for 5 days using analysis quality COAMPS wind stresses. This procedure does not guarantee that the mass fields at the end of the 5-day prognostic run are identical to the analyzed mass fields, as is the case for the POP model.

RESULTS

A series of 5 experiments have been designed for the global forecast system to assess the relative merits of the various oceanographic observing systems. The experiments include assimilating only surface observations, surface and subsurface data, and finally all data sources including MODAS synthetic BTs. In these experiments, permutations of combinations of the available observation systems are used in the analysis of the ocean state in which one observing system at a time is excluded from the analysis. This procedure provides an estimate of the impact of the omitted system on the quality of the forecast issued from the analysis. A forecast run of POP forced by NOGAPS, starting from the same ocean analysis initial conditions, is used as the control run. The 3D MVOI code has built-in data denial options that help facilitate these observing system experiments. Execution of the experiments is still underway.

As part of the COAMPS re-analysis effort a series of cycling, data assimilative NCOM runs in the Mediterranean Sea were performed. All runs begin with the same initial model state valid 1 Oct 1999. In one run, all observation data sources including MODAS synthetic BTs are used in the analysis. In a second run, all data sources except MODAS synthetic BTs are used in the analysis. There are two types of control runs. The first control run is an analysis-only run where the analysis is cycled on itself without a model forecast. The second control run is a pure forecast run where NCOM is forced by COAMPS re-analysis fields without any ocean data assimilation. Verification of the various runs is performed by comparing NCOM forecast and analysis fields with a set of independent XBT measurements taken as part of the Mediterranean Forecast Systems Pilot Project (MFSPP) during October 1999. The locations of the MFSPP XBTs used in the verification are shown in Figure 1. Figure 2 shows the RMS error, mean bias and data counts for the verification of the various model and analysis runs against the MFSPP XBTs. The largest RMS and mean bias errors are at the depth of the mixed layer (30 – 70 M). There is a clear pattern of reduction in error at mixed layer depths from the analysis cycling on itself (persistence) to the data assimilative case that was denied MODAS synthetic BTs. The NCOM model forecast run shows skill in predicting mixed layer depths over that of a persistence forecast, and forecast skill is improved when the model is run in a data assimilative mode. This pattern is expected for a model cycling with an analysis in a sequential incremental update cycle. However, RMS and mean bias errors are the greatest at mixed layer depths when MODAS synthetic BTs are used as a source of observations in the analysis. This result is due to the fact that the MODAS synthetic BTs are computed using a climatologically based mixed layer depth model that has marginal skill predicting time dependent mixed layer depths.

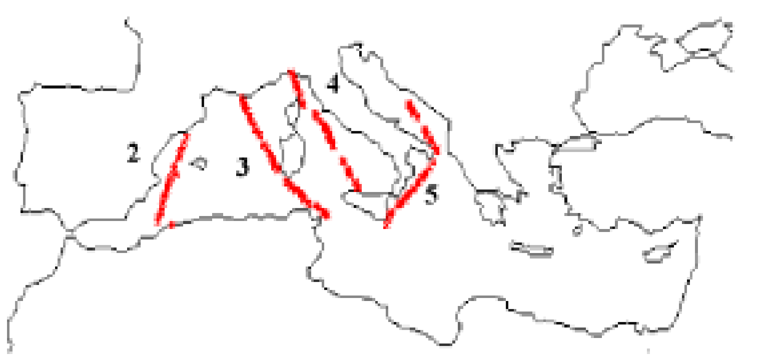

Figure 1. Location of MFSPP XBT drops during October 99. The numbers refer to the various sampling legs occupied at various times during the month.

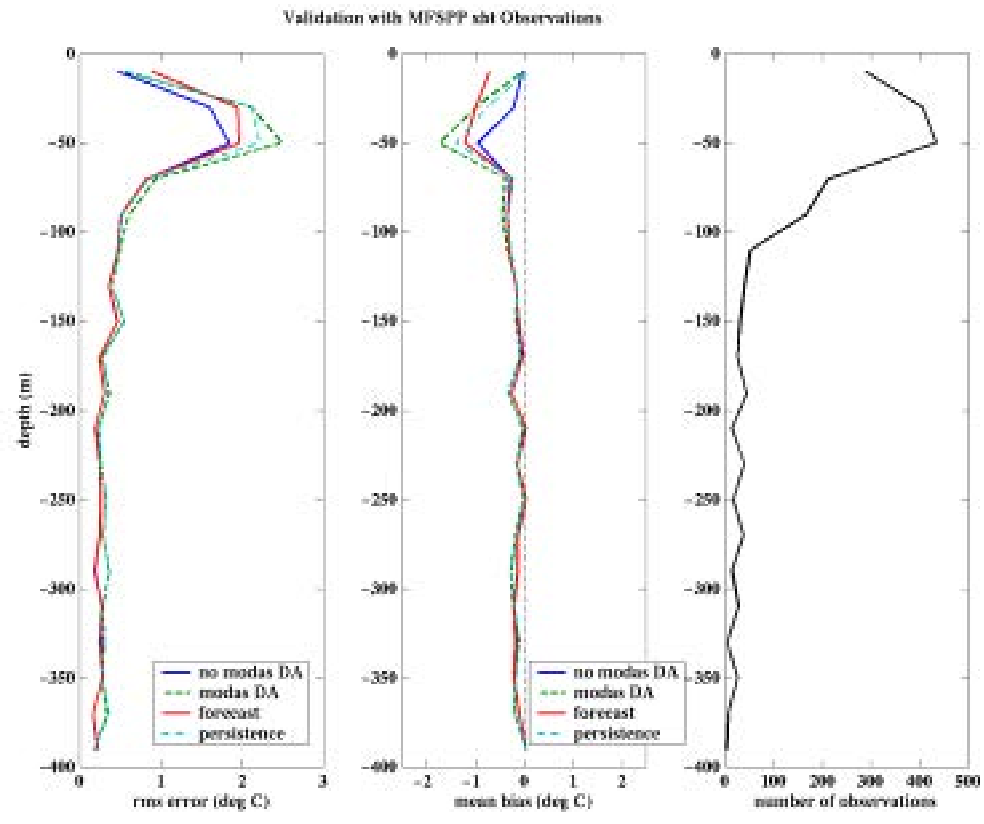

Figure 2. Verification statistics of the various analysis and forecast runs against the MFSPP XBTs.

Sea level data from satellite altimeters is presently assimilated in the 3D MVOI via MODAS synthetic BTs. The MODAS synthetics are computed from pre-defined statistical relationships between sea level anomalies and temperature at depth derived from historical profile observations. This approach has limitations in that the statistics depend on adequate sampling of the historical profile data, and the fact that the temperatures are constructed by computing anomalies from a static climatology. Repeated assimilation of MODAS synthetic BTs over time will thus continually force the model forecast state to reflect the MODAS climatology, particularly at depth.

A modification of the dynamical method of Cooper and Haines (1996) is being developed for direct assimilation of altimeter data in the 3D MVOI. In this new method, geopotential increments at depth are computed consistent with the change in sea surface height from the model forecast measured by the altimeter. Velocity increments are then computed from the geopotential increments using the multivariate correlations, and a simple cost function is used to compute increments of temperature and salinity that correspond to the geopotential increments. One advantage of this approach is that the method is model independent and does not require any pre-processing steps or statistical calculations. The method relies on model dynamics for *a priori* information and is therefore more adaptable to the particular model state at any one time. A potential disadvantage is that the method is based on local adjustment of the existing water column in the vertical and may not represent a realistic physical process. Further, the method cannot explicitly correct stratification in the model that is initially incorrect. There may also be problems at higher latitudes if the altimeter sea level anomaly data contain significant barotropic signals. This later issue is also a problem in the MODAS synthetic BT approach. Test and evaluation of this new approach to direct assimilation of satellite altimeter data in the 3D MVOI is underway.

IMPACT/APPLICATIONS

Multivariate analysis of mass and velocity in the ocean is new. In an ocean MVOI analysis, mass and velocity are consistent with simple linear dynamic constraints, and the constraints are built right into the algorithm. Enhanced ability to define the littoral battlespace environment through the use of a coupled air/ocean-analysis/model system will provide Navy forces with a unique capability to exploit the environment to their tactical advantage.

TRANSITIONS

The 3D MVOI analysis is installed in the COAMPS developmental software configuration management system at NRL Monterey and is being transitioned to FNMOC via an Administrative Model Oversight Panel (AMOP) process started in FY01. All developmental and operational users of COAMPS routinely utilize the ocean data assimilation component. These users include the Navy operational centers, Navy Laboratories, the National Laboratories, and several universities.

RELATED PROJECTS

This project complements several ongoing ONR funded projects on Global Air-Ocean Coupling Development and Studies (N0001401WX20988) and Air/Ocean Model and Prediction System Development (N0001401WX20516) at NRL Monterey and at NRL Stennis.